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Role of Tillage, Thiamethoxam Seed Treatment, and Foliar Insecticide Application for Management of Thrips (Thysanoptera: Thripidae) in Seedling Cotton

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Abstract

Thrips are early-season pests of cotton and can cause yield and stand losses if not managed. Strip tillage into a winter cover crop, use of a neonicotinoid seed treatment, and foliar insecticide applications are all reliable pest management tactics, but how these methods interact with each other in a thrip–cotton agroecosystem needs to be further understood. A 2-yr field study was conducted to compare thrip counts and thrip-induced plant injury as a function of tillage practice (conventional vs strip tillage with heavy rolled rye), thiamethoxam seed treatment, and foliar insecticide application for managing thrips in cotton. Adult and nymph density, seedling biomass, true leaf formation, stand count, and lint yield were assessed. Results indicate that heavy rolled rye was effective for mitigating thrips on seedling cotton. On conventionally tilled fields, the neonicotinoid seed treatment and a foliar insecticide application were necessary for maximizing yield. Spinetoram was more efficacious than either acephate or cyantraniliprole for management of immature thrips; however, there were no yield effects attributed to foliar insecticide application. These data suggest that growers can mitigate early-season thrips using both cultural and chemically based management tactics.

Key words: rolled rye, neonicotinoid, spinetoram, acephate, cyantraniliprole

Thrips are the most consistent economic pests of seedling cotton (*Gossypium hirsutum* L.) (Malvaceae) in the southeastern United States. The most common species infesting cotton in this region is tobacco thrips, *Frankliniella fusca* (Hinds) (Thysanoptera: Thripidae) (Toews et al. 2010, Cook et al. 2011, Stewart et al. 2013). Typically, *F. fusca* adults and nymphs prefer cotton seedlings and flowers over other plant tissues, and both adults and nymphs show lowest preference for upper canopy leaves compared with middle and lower canopy leaves (Reay-Jones et al. 2017). Female thrips oviposit within the host plant leaf tissues, followed by two plant-feeding larval stages, and then pupate in soil (Cook et al. 2011). Active life stages of this piercing-sucking pest feed on the contents of plant epidermal cells (Harrewijn et al. 1996). Due to loss of cell contents, damaged plant tissue appear silvery and leaf margins are curled; severe infestations can result in death of the apical meristem (Telford and Hopkins 1957, Reed 1988, Reed and Reinecke 1990). Thrip injury can also lead to excessive vegetative branching due to loss of apical dominance and reduced root mass (Gaines 1934, Roberts et al. 2009). Cooler environments promote slow-growing cotton seedlings and magnify the effects of thrip injury (Bacheler 2012).

Thrips overwinter in nonagronomic hosts and disperse into cultivated crops such as cotton, peanut [(*Arachis hypogaea* L. (Fabaceae)], tobacco [*Nicotiana tabacum* L. (Solanaceae)], and onion [(*Allium cepa* L. (Amaryllidaceae)] (Eckel et al. 1996, Larentzaki et al. 2007, Beaudoin and Kennedy 2012, Knight et al. 2015). *Frankliniella fusca* overwinter in common chickweed [(*Stellaria media* L. Cyrillo (Caryophyllaceae)], knawel weed [(*Scleranthus annuus* L. (Caryophyllaceae)], and spiny-leaved sowthistle [(*Sonchus asper* L. (Asteraceae)] (Groves et al. 2001). In addition, 16 winter hosts of *F. fusca* in Georgia have been identified (Beckham et al. 1971). Larentzaki et al. (2007) found that onion thrips, *Thrips tabaci* Linderman (Thysanoptera: Thripidae), also found in cotton, overwinter in the soil within and near onion fields and are associated with weeds such as pigweed [(*Amaranthus hybridis* L.(Amaranthaceae)] and lamb's quarters [(*Chenopodium album* L. (Amaranthaceae)].

Overall, thrips are regarded as economic pests of presquaring cotton in the United States and insecticide application is recommended as an effective management strategy (Hopkins et al. 2002). Per Extension-recommended practices, foliar applications should only be initiated up to the fourth true leaf stage (Cook et al. 2011). A gain of 381 kg lint/ha was found in insecticide treatments such as foliar, in-furrow, and seed applied, compared with nontreated plots (Herbert 2002). *Frankliniella fusca* is relatively more susceptible to

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insecticides, such as imidacloprid, compared with other thrip species found in cotton (Stewart et al. 2013). Insecticide application at planting, including in-furrow granular, in-furrow liquids, and seed treatments, is generally superior to foliar-applied materials (Jones et al. 2017a,b). Neonicotinoid seed treatment increased yield by US$141 per ha compared with fungicide-only-treated seeds in the midsouthern states (North et al. 2018). However, supplemental foliar application and planting into crop residues can be useful in managing field thrip populations. Siebert et al. (2016) found that thrip suppression from a foliar application of spinetoram (Group 5, IRAC 2018) at 13–26 g a.i./ha is comparable with commercial standards and exhibits better performance than spinosad for the suppression of *F. fusca* and *Th. tabaci* as long as extremely high thrip population (>269-fold threshold of one thrip per plant) is not reached.

Huseth et al. (2016) reported that *F. fusca* has developed variable resistance to both imidacloprid and thiamethoxam (Group 4A, IRAC 2018) across midsouthern and southeastern United States. Recent data from North Carolina and Virginia document neonicotinoid-resistant *F. fusca* (Huseth et al. 2017). Additional selection pressure due to neonicotinoid application to control mid- to late-season pests may be causing further resistance development in the most dominant thrip species (Luttrell 1994, Reay-Jones et al. 2017). Acephate (Group 1B, IRAC 2018) foliar application has been adopted to manage resistant *F. fusca* on seedling cotton (Akin et al. 2010, 2012).

Use of winter cover crops and strip tillage into terminated winter cover crops [rye, *Secale cereal* L. (Poaceae); wheat, *Triticum aestivum* L. (Poaceae); and crimson clover, *Trifolium incarnatum* L. (Fabaceae)] can provide additional population mitigation of early-season thrips (Toews et al. 2010, Knight et al. 2015). Hand-applied rye residue cover with high biomass can significantly reduce thrip damage in cotton when compared with moderate, low, and no rye cover (Olson et al. 2006). Also, a high biomass of strip-tilled rolled rye is not only effective in weed suppression of notorious weeds such as those belonging to *Amaranthus* spp., but also effective in thrip suppression (Knight et al. 2015, Webster et al. 2016). On the contrary, early planting in conventionally tilled cotton fields constitutes a high-risk environment for thrip infestation and is likely to require supplemental foliar applications (Stewart et al. 2013). Due to increasing insecticide resistance to neonicotinoids and loss of registrations of carbamate and organophosphate classes, the objectives of this study were to elucidate the complimentary role of tillage practice (conventional vs strip tillage with rolled rye), seed treatment (basic fungicide vs neonicotinoid), and foliar application (none/acephate/cyantraniliprole/spinetoram) for managing thrips in cotton.

Materials and Methods

Field experiments were conducted during 2015 and 2016 at the Coastal Plain Experiment Station located at the University of Georgia-Tifton Campus (31.5239, –83.5480). All cotton was grown under irrigated conditions and evenly fertilized following Extension-recommended practices. The field was planted during the first week of May for both years of study. Plots were four rows wide (0.91-m row spacing) by 12 m long and planted with commercially available cotton varieties (var. DP 174 RF in 2015 and DP 1522 B2XF in 2016) at a rate of 107,593 seeds/ha. Tillage consisted of either strip tilled (stripped into heavy rolled rye) or conventionally tilled. Briefly, strip-tilled plots were planted with rye in mid-November at seeding rate of 67.25 kg/ha using a no-till grain drill; those plots were treated with 67.25 kg/ha of ammonium nitrate in late February to facilitate biomass production. Rye rows were established on 17.8-cm centers. The plots containing rye were chemically terminated with glyphosate (2.9 liters/ha) when they reached a height of ~2 m on 10 April during both years and immediately rolled with a cylindrical drum roller to form a horizontal mulch layer. Conventionally tilled plots were first harrowed, and then both strip tilled and conventionally tilled were prepared with a single pass using a strip till implement with in-row subsoil shanks adjusted to a depth of 40.6 cm.

Two additional treatment variables were examined simultaneously with tillage. The two seed treatments included in this study were fungicide only, and fungicide + thiamethoxam (0.375 mg/seed; hereafter mentioned as thiamethoxam seed treatment). Finally, foliar insecticide application was applied when 90% of emerged plants had the first true leaf bud; this occurred generally at 13–14 d post-emergence. Four types of foliar applications were tested, including cyantraniliprole (Exirel, DuPont, Wilmington, DE; Group 28, IRAC 2018) at 0.95 kg/ha, spinetoram (Radiant SC, Dow AgroSciences, Indianapolis, IN) at 1.05 kg/ha + Dyne-Amic (Helena Chemical Co., Collierville, TN) at 0.625% v/v, and acephate (Orthene 97, AMVAC Chemical Corp., Los Angeles, CA) at 0.21 kg/ha, or not treated.

Thrip Infestations

Adult and nymph thrips were evaluated at appropriate seedling cotton growth stages. For sampling adults, five randomly selected plants per plot were removed from the soil and immediately inverted in 0.47-liter glass jars partially filled with 70% ethyl alcohol, following the methods of Toews et al. (2010). Collected thrips were sieved out of the alcohol over a 125-µm sieve and enumerated under a dissecting microscope. Nymphs were sampled using the same procedures described earlier, but samples were obtained at 21 d after planting (DAP). Because there were few adults in the 21 DAP samples and very few nymphs in the 14 DAP samples, the authors only analyzed adults at 14 DAP and nymphs at 21 DAP.

Plant Evaluations

A comprehensive sampling program was implemented to characterize treatment effects on the growing and mature cotton plants. At 28 DAP, the number of true leaves that were expanded to a diameter of at least 2 cm was enumerated on five plants per plot. Similarly, the number of plants in 12 m of row was counted from each plot. At 42 DAP, five representative plots were clipped at the soil surface and pooled into paper bags by plot. The bags were brought to the laboratory where they were dried in a laboratory oven for 48 h at 50°C, and then the dry plants were weighed on a laboratory microbalance. Finally, lint yield in each plot was estimated by first chemically defoliating the crop and then mechanically harvesting the center two rows from each plot with a two-row mechanical spindle picker that was modified to collect the seed cotton from each plot into bags. After weighing the bag, lint was estimated by assuming a lint fraction of 40%.

Data Analysis

The experimental design was a three-way analysis of variance arranged in a split plot with tillage as main plot factor and seed treatment and foliar application randomized at the subplot level (four replications per treatment combination). Regardless of response being analyzed, data from both years were modeled together using a single analysis (PROC MIXED, SAS Enterprise Guide v. 6.1, SAS Institute, Cary, NC). Random effects in the model included the year of study and replication. Independently analyzed response variables included adult thrips counts at 14 DAP, immature thrips counts at 21 DAP, true leaf count and stand count at

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28 DAP, aboveground dry plant weight at 42 DAP, and lint yield at harvest. Counts of immatures and adult thrips were first transformed using the square root transformation to meet assumptions of normality (Zar 1999). Interactions among fixed effects were examined at $\alpha = 0.10$, whereas main effects not involved in interactions were compared and separated using the LSMEANS comparison procedure at $\alpha = 0.05$. In cases where there were differences among more than six treatment combinations, the Tukey mean separation procedure was used (J. W. Tukey, unpublished data). Although all possible interactions (both three way and two way) were examined prior to main effects, only those interactions that were statistically significant are described in the results. Means in figures and in the text are presented with SEM.

Results

Thrip Infestations

Analyses of adult thrip counts at 14 DAP indicated there were no interactions between tillage practice and seed treatment ($F = 0.04$; df = 1, 110; $P = 0.8511$), but both of the main effects were significantly different. Approximately 32% more adult thrips were observed in plots receiving conventional tillage (34.0 ± 2.5 thrips) compared with rolled rye plots (24.6 ± 2.2 thrips; $F = 18.60$; df = 1, 3; $P = 0.0230$). Similarly, plots that received a thiamethoxam seed treatment exhibited 16% more adult thrips (31.7 ± 2.2) compared with fungicide-only seed treatment (27.0 ± 2.6; $F = 11.29$; df = 1, 110; $P = 0.0011$).

There was no three-way interaction for analysis of thrip nymph counts at 21 DAP, but there were significant effects attributed to tillage by foliar application (Fig. 1). Data show that there were exactly twice as many nymphs on conventionally tilled plots (48.0 ± 4.8 thrips) compared with rolled rye plots (24.1 ± 2.4 thrips). However, the response of foliar treatment was not consistent between tillage types. Spinetoram provided maximum observed suppression across tillage types, whereas acephate and cyantraniliprole suppression were proportional to the number of thrips observed in plots not receiving a foliar treatment.

Plant Evaluations

True Leaf Development

There were significant interactions for the response number of true leaves at 28 DAP. For example, the interactions between tillage and seed treatment ($F = 9.29$; df = 1, 99; $P = 0.0030$), as well as tillage and foliar application ($F = 4.76$; df = 3, 99; $P = 0.0038$) were significant. The conventionally tilled plots with thiamethoxam seed treatment (5.4 ± 0.1), rolled rye plots with thiamethoxam seed treatment (5.3 ± 0.1), and rolled rye plots with fungicide-only seed treatment (5.2 ± 0.1) exhibited more true leaves compared with conventionally tilled plots with fungicide-only seed treatment (4.7 ± 0.2). These interactions were evident because there were fewer leaves in plots that were grown on conventional tillage with no foliar spray.

Plant Stand

There were no interactions and few significant differences among main effects when analyzing for differences in stand counts. The only parameter affecting the cotton stand count was seed treatment ($F = 5.89$; df = 1, 99; $P = 0.0170$). Plots with fungicide-only seed treatment exhibited an 11% higher stand count (94.7 ± 3.1) compared with plots with thiamethoxam seed treatment (84.5 ± 4.4).

Dry Plant Weight

There were no interactions or main effects attributed to tillage or foliar application. However, dry plant weight was affected by seed treatment ($F = 22.59$; df = 1, 99; $P < 0.0001$). Significantly more aboveground biomass was accumulated in plots with thiamethoxam seed treatment (51.5 ± 2.2 g) versus plots with fungicide-only seed treatment (39.2 ± 1.8 g), a 27% increase.

Yield

When examining for differences in lint yield, there was an interaction between tillage and seed treatment ($F = 3.97$; df = 1, 99; $P = 0.0490$); yield in conventionally tilled plots with thiamethoxam seed treatment was greater than all other treatment combinations (Fig. 2). Within rolled rye plots, yield was similar between fungicide-treated

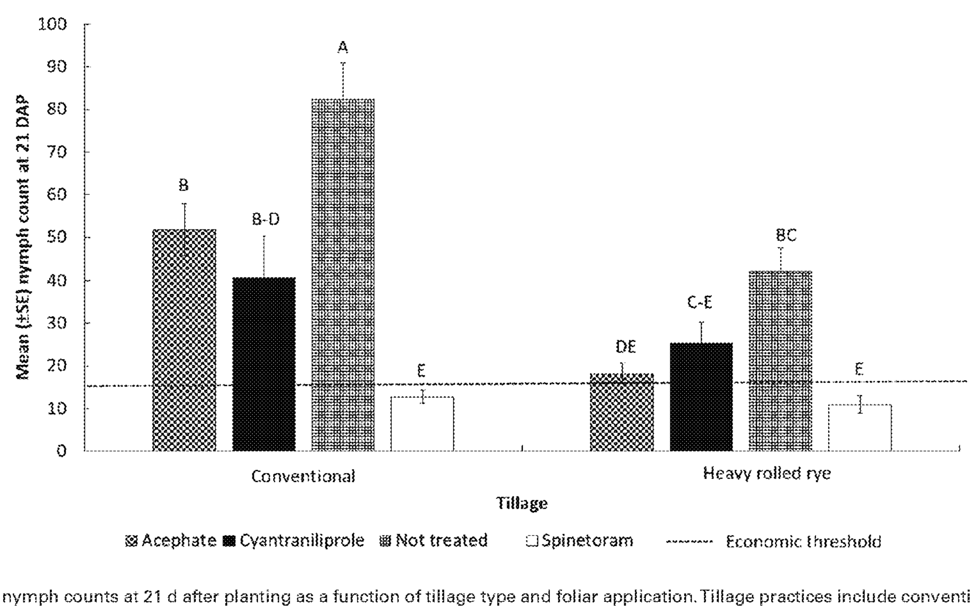

Fig. 1. Mean (± SE) nymph counts at 21 d after planting as a function of tillage type and foliar application. Tillage practices include conventional and strip tillage into heavy rolled rye. The four foliar applications include cyantraniliprole, spinetoram, acephate, and not treated. Means with different letters are significantly different ($P < 0.05$; LSMEANS).

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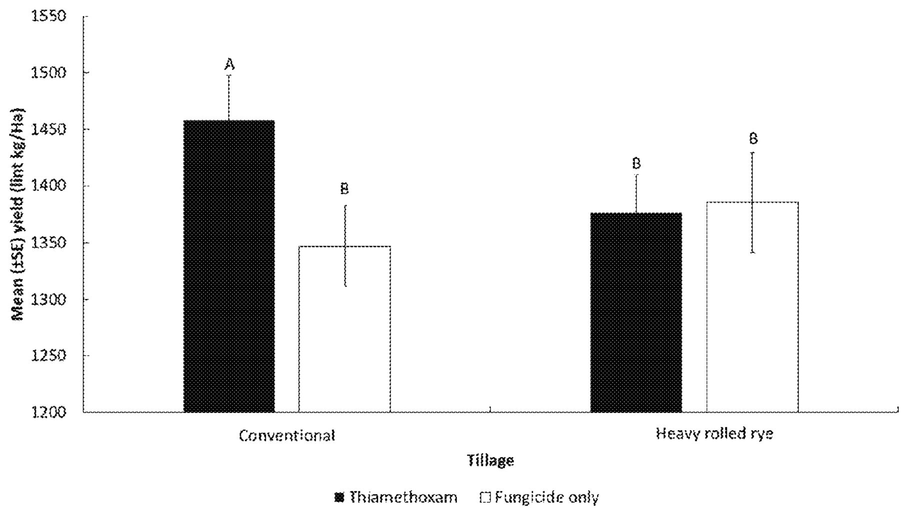

Fig. 2. Mean (± SE) lint yield (kilogram per hectare) as a function of tillage type and seed treatment. Tillage practices include conventional and strip tillage into heavy rolled rye. The two seed treatments include fungicide only and fungicide + thiamethoxam. Means with different letters are significantly different ($P < 0.05$; LSMEANS).

and fungicide + thiamethoxam-treated seed treatments. However, fungicide + thiamethoxam-treated seeds in the conventionally tilled plots yielded 8% (111 kg/ha) more lint than fungicide-only-treated plots. There were no other interactions or significant main effects for this response variable.

Discussion

These data conclusively showed that strip tillage in a heavy rolled rye cover crop decreased thrip infestations in seedling cotton. The efficacy of strip tillage as a stand-alone strategy in managing thrips has been shown to significantly reduce thrip nymph populations from cotton planted in strip-tilled plots with winter cover crops including crimson clover, *Tr. incarnatum* L. (Fabaceae) wheat, *T. aestivum* L. (Poaceae), or rye (Toews et al. 2010, Knight et al. 2015). Higher average seasonal abundance of thrips in conventionally tilled plots versus strip-tilled plots was also reported from cotton fields in Texas and tobacco fields (All et al. 1992, Lohmeyer et al. 2002, Parajulee et al. 2006). Furthermore, these data suggest that cotton cultivated under heavy rolled rye cover did not require additional thrip management inputs, such as thiamethoxam seed treatment or foliar insecticide applications. Conversely, adult thrip populations on conventional tillage with fungicide-only-treated seed reduced leaf development and biomass accumulation such that resulting seedlings could not support the same populations of immatures as observed on seedlings from thiamethoxam-treated seeds. There are no reports in the literature of thiamethoxam seed treatment increasing seedling biomass in the absence of thrip infestations. Therefore, these data strongly suggest that initial populations of adult thrips were directly responsible for decreasing seedling performance.

Thiamethoxam attacks the nervous system of insects by acting as a nicotinic acetylcholine receptor competitive modulator. Greenberg et al. (2009) reported that foliar application of acephate at one to two true leaves was effective for thrip suppression in cotton. Acephate is an organophosphate that attacks the insect nervous system by acting as an acetylcholine esterase inhibitor. Cyantraniliprole, an anthranilic diamide insecticide that affects the nervous system through calcium metabolism, was also efficacious in thrip suppression. Other studies have also reported thrip suppression by inclusion of cyantraniliprole in their treatment programs for various crops (Jacobson and Kennedy 2013, Bielza and Guillén 2015, Cluever et al. 2016). By comparison, both acephate- and cyantraniliprole-treated plots only reduced the number of nymphs to the same level as cotton grown under strip tillage with no foliar applications.

The present study shows that the requirement of thrip suppression inputs in conventionally grown cotton is clearly greater than required for heavy rolled rye. This may also be true for other production inputs as weed suppression in strip-tilled plots is superior to conventionally tilled crops that require additional herbicide applications, especially after heavy rainfall (Rapp et al. 2004, Mischler et al. 2010, Smith et al. 2011). Even though weed control alone may not justify the cost of maintaining a cover crop, there are additional ecosystem services, such as soil health improvement and recruitment of natural enemies, that a heavy rolled rye cover provides (Mochizuki et al. 2008, Koch et al. 2015, Rivers et al. 2017).

It is noteworthy that crop yields were maximized under heavily managed conditions with conventional tillage. However, the cost of the additional inputs may not justify the increased yield every year. Response of cotton to thrip infestation is influenced by environmental conditions (Cook et al. 2013); therefore, some variation in impact of management strategies may vary from year to year. However, yield was consistent across all treatment inputs on rolled rye plots. Much more disparate variability in yield on conventionally tilled plots suggests that there is more risk to this type of production. For example, growers may not be able to react in a timely manner to manage thrip due to excess rainfall or logistics of treating many fields at the appropriate time. Higher lint yield was achievable in conventionally grown cotton, cultivated under high input circumstances. For example, conventionally tilled cotton fields benefitted from thiamethoxam seed treatment as well as foliar spray (specifically that of spinetoram), to manage thrip adults and nymphs and to significantly boost yield.

Interestingly, there was an increased stand count in fungicide-only plots, but this did not translate into higher yield. Therefore, stand count alone did not provide adequate information about the health of the plants; however, other plant parameters such as number of true leaves and dry biomass accumulation were more helpful in evaluating thrip control. These data also suggest that fewer healthy plants are able to compensate for differences in stand loss. Bednarz et al. (2000) reported that fruit retention, boll size, and mean net assimilation rate from first flower to peak bloom were inversely

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proportional to cotton plant population density. Initially, insecticide seed treatment alone was effective in helping plants develop true leaves; however, foliar application (especially spinetoram) was also necessary to continue healthy true leaf formation (photosynthetic capacity), further improving the performance of plots with neonicotinoid seed treatment. Spinetoram also affects the insect nervous system by acting as a nicotinic acetylcholine receptor allosteric modulator. In fact, only fungicide-treated seed without a foliar spray separated from the remaining treatment combinations. Although there were significant differences in thrip suppression as a function of foliar application, these differences were not evident in lint yield. These data suggest that any of the foliar insecticides tested here provide adequate suppression for maximizing yield. The similar yield data across foliar applications suggest that cotton is able to compensate for early-season damage over the full season.

The data suggest that the thiamethoxam seed treatment provided a better start for the seedling plants than fungicide-only-treated seed followed by a foliar spray. In fact, the thiamethoxam seed treatment provided a 27% increase in biomass across tillage types. This difference is probably explained by the fact that adult thrips begin colonizing the seedlings the day they emerge from the soil (Cote et al. 2002). Although foliar applications can be efficacious, they are not as effective as the seed treatment that was absorbed into the plant tissues during germination. Thiamethoxam was also more effective in reducing adult thrips in soybeans (Reisig et al. 2012); however, no positive yield response was evident. Other than providing pronounced systemic insecticidal activity against early-season pests, neonicotinoid seed treatment may benefit plant vigor in other ways (Wilde et al. 2004, Moser and Obrycki 2009). Larsen and Falk (2013) found that neonicotinoid seed treatment improved the germination and freezing tolerance of spring wheat in Canada. No deleterious effects due to neonicotinoid seed treatment to intact cotton seeds have been found by other studies (Prasanna et al. 2004).

Other studies have also reported the efficacy of spinosyns for foliar-applied rescue treatments. Lopez et al. (2008) found that spinosad foliar spray was most effective in maintaining the minimum thrips per plant, compared with organophosphates and neonicotinoid sprays. Furthermore, Lopez et al. (2008) also found that spinosad rates can be decreased below the label rate when the water volume was increased from 19 to 47 liters/ha. Both spinosad and acephate foliar applications are effective in controlling thrips in greenhouse plants (Cloyd and Sadof 2000).

Neonicotinoid insecticides, including acetamiprid, clothianidin, imidacloprid, nitenpyram, dinotefuran, thiacloprid, and thiamethoxam, have been marketed since the 1990s (Thany 2010). Neonicotinoid use patterns, including thiamethoxam seed treatments, are under regulatory and political scrutiny. For example, declines in pollinator health as a result of neonicotinoid seed treatment applications are widely reported in the literature (Gill et al. 2012, Krupke et al. 2012, Jiang et al. 2018). The US EPA (2014) reports that imidacloprid is a potential threat to bees. In response, both Canada and the European Union have posed severe regulations restricting these compounds in agricultural crop pest management (Reg. (EU) No. 485/2013, 2013; EFSA 2015a,b,c; PMRA 2017). Finally, under the Pollinator Protection Act of 2016, Maryland is the first U.S. state to ban consumer use of neonicotinoid insecticides (GAM 2016). Although an outright ban on neonicotinoids in the United States is unlikely, if enough states restrict their use, it will have the same effect as a ban because product labels would vary widely among states, even in those that grow the same crops. Here, data show that there were measurable plant health benefits to the use of thiamethoxam-treated seed for seedling thrip protection from cotton. However, in the absence of an available seed treatment, growers could also manage thrip populations using strip tillage with heavy rolled rye and winter cover crops or timely application of efficacious foliar-applied insecticides. Neither of these practices is neonicotinoid seed treatment alternatives: the use of cover crops requires planting a fall cover crop and different tillage equipment than conventional tillage equipment; furthermore, foliar sprays can be difficult to apply at the correct time. These data indicate that growers could adequately manage seedling thrips in cotton, regardless of increased insecticide resistance or changes in the regulatory environment.

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